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DEVELOPMENT OF ALL-POSITION COATED WELDING ELECTRODE OF CHROMIU--ETC(U)

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FINAL REPORT

ON CONTRACT N00014-74-C-0139

DEVELOPMENT OF ALL-POSITION COATED WELDING ELECTRODE OF CHROMIUM-ENRICHED CUPRONICKEL ALLOY

by

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January 31, 1977

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A three-phase program for the development of a satisfactory all-position chromium-enriched cupronickel electrode was proposed by Arcos Corporation and accepted by the government. In Phase I experimental electrodes were produced and screened for welding operation by use of horizontal and vertical fillets. The electrodes deemed most promising in the operational tests were then checked initially for weld metal soundness via test 8a, the

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cont vertical plate of specification MIL-E-22200/4B and Arcos modified test 8a, a simulated pipe test.

In Phase II, the best electrodes from Phase I testing were evaluated for conformance to tentative mechanical properties and weld metal composition, and weld metal soundness in the flat position by use of test 3 of specification MIL-E-22200/4B.

In Phase III, pipe welds were made in 4" NPS class 700 chromium-enriched cupronickel pipe with electrodes culled by use of Phase I and II tests. The procedure used was test 9 of specificiation MIL-E-22200/4A interim amendment 3.

A total of (50) formulas were made and evaluated. A successful electrode with excellent operational characteristics was developed and a demonstration was made before an NSRD representative.

Recommendations for further work were presented.

ABSTRACT

A three-phase program for the development of a satisfactory all-position chromium-enriched cupronickel electrode was proposed by Arcos Corporation and accepted by the government. In Phase I experimental electrodes were produced and screened for welding operation by use of horizontal and vertical fillets. The electrodes deemed most promising in the operational tests were then checked initially for weld metal soundness via test 8a, the vertical plate of specification MIL-E-22200/4B and Arcos modified test 8a, a simulated pipe test.

In Phase II, the best electrodes from Phase I testing were evaluated for conformance to tentative mechanical properties and weld metal composition, and weld metal soundness in the flat position by use of test 3 of specification MIL-E-22200/4B.

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FINAL REPORT

ON CONTRACT N00014-74-C-0139

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OF

CHROMIUM-ENRICHED CUPRONICKEL ALLOY

INTRODUCTION

Arcos had preliminary discussions regarding chromium-bearing all-position cupronickel electrodes in early 1972 with Mr. Ronald Leopold, then with the Naval Ship Research and Development Center. Arcos was interested in this project and subsequently proceeded to do some preliminary development work gratis. This work culminated in some 1/8" sample electrodes sent to Mr. Leopold in December, 1972. These electrodes were eventually evaluated and deemed to have sufficient merit to warrant a proposal on our part for a contract to do further work.

As a result of our submission of a proposal for development of an all-position coated welding electrode of chromium-enriched cupronickel alloy, dated June 29, 1973, we were awarded contract no. N00014-74-C-0139 dated March 1, 1974 to go forward with the work as outlined in the proposal.

The proposal outlined a three-phase approach as listed herewith:

PHASE I - Coating development to insure sound welds made with 1/8" electrodes as determined by test 8a of MIL-E-22200/4B.

PHASE II - Metallurgical adjustments to weld metal chemistry via coating additions of metallics. Composition of deposited weld metal and mechanical properties to be determined in accordance with test no. 3 of MIL-E-22200/4B, to check ability to meet chemical and mechanical properties criteria.

PHASE III - After completion of Phases I and II, Phase III will show ability of the electrode to meet radiographic standards for pipe welds in accordance with test no. 4 of MIL-E-22200/4A, Interim Amendment 3, using 4" NPS class 700 pipe.

Appropos of the three-phase plan, we recognized that, once the work progressed, the three phases would necessarily overlap and require back-tracking from time to time as feedback from Phases II and III results might indicate need for more Phase I work. However, the three-phase plan seemed to be a good framework on which to build and work was scheduled accordingly as the requisite chromium enriched cupronickel plate and wire were supplied by the government.

PHASE I - COATING DEVELOPMENT TO INSURE SOUND WELDS MADE WITH 1/8" ELECTRODES AS DETERMINED BY TEST 8a OF MIL-E-22200/4A

Criteria for Production Characteristics of Electrodes to be Developed

Since no practical purpose can be served by developing an electrode which is destined from its conception to be a laboratory curiosity, the following criteria for production characteristics of electrodes to be developed for this project were adopted:

1. The electrode must be capable of being satisfactorily produced on standard production equipment now available.

2. All coating ingredients must be readily available and preferably from several reliable sources.

3. All coating ingredients to be examined carefully from a "value" viewpoint to guide final selection toward greater value at minimum cost possible while maintaining fully adequate quality.

4. Coatings must have sufficient mechanical strength to be shipped in standard commercial or military containers and arrive at destination without unacceptable coating damage.

All coatings tried herein met these criteria. However, the foregoing criteria were not so strictly construed as to automatically eliminate without trial, promising ingredients which may not meet the criteria at present but which might be developed to do so.

Coating Formulae Composed of Unfused Natural and Synthetic Compounds and Metallics

Since the formula used on the electrodes submitted in December of 1972 showed considerable promise, and was composed of unfused natural and synthetic compounds as well as metallics, it was used as a point of departure for conceptual work and subsequent electrodes prepared for this project.

Ideally, an electrode covering should give the electrode the following characteristics:

1. Easy striking and re-striking.
2. Stable, soft, easily controlled arc.
3. Low spatter.
4. Easy, clean slag removal
5. Good penetration.
6. Clear, well-defined weld pool.
7. No undercut.
8. Excellent wetting and wash of the base metal by the molten weld metal.

9. Acceptable bead shape, not excessively convex or concave.
10. Sound, ductile weld metal.
11. Possession of all preceding attributes in all welding positions.

While the electrodes previously supplied represented a good start toward meeting this formidable list of requirements, definite improvement was needed; hence, a number of formulae utilizing unfused natural and synthetic compounds as well as metallics were conceived, produced, and tested.

Coating Formulae Composed of Unfused Natural and Synthetic Compounds, Metallics and Fused Synthetic Compounds

Specially fused synthetic compounds now commonly available often operate in electrode coatings to provide to a marked effect the desirable electrode qualities previously listed. This seems to be especially true in highly alloyed weld metals. Consequently, a series of formulae incorporating from one to three fused synthetic compounds were made and tested.

Investigation of Different Binders

The usual sodium and potassium silicate binders or combinations thereof were used. Since different binder combinations in electrode coatings may have profound effects upon electrode operation with regard to slag removal, bead shape, undercut, arc stability, out-of-position operation, etc., a number of different binder combinations were tried. All were reasonably good but several were outstanding. These then were utilized in the later, more refined coating formulae used for soundness tests.

Investigation of Different Deoxidizing and Refining Metallics

Since the selection of the proper type and blend of potent deoxidizing and refining metallics usually has a profound effect on weld metal soundness in cupronickel alloys, careful attention was given to this aspect of coating formulation. As a result, several satisfactory systems were developed and applied in electrodes used to make soundness tests.

Investigation of Coating to Core Area Ratios

The coating diameter determines the ratio of the coating area to the core wire area. Because the coating to core ratio selected may profoundly affect electrode operation, weld metal composition and mechanical properties, this factor was given careful study and various ratios within what experience has shown are workable limits, were explored.

Investigation of Formulae Using Standard 70-30 Cupronickel Core Wire and Supplying Weld Metal Chromium-Enrichment Via the Coating

There are two valid reasons for adding alloying ingredients via the coating. One is that improved electrode operating characteristics and improved weld metal properties may be attained. The other is economic - alloying through the coating may be cheaper; also, one core wire can service several different requirements and circumvent long deliveries of alloyed core wire. Consequently, several formulae were prepared in consideration of these aspects.

METHODS AND MATERIALS FOR EVALUATION OF ELECTRODE OPERATION AND WELD METAL SOUNDNESS

Electrode Operation

The traditional means for preliminary screening of experimental all-position electrodes is the use of horizontal and vertical fillets. This method seemed ideally suitable for this project and was therefore adopted. In order to conserve the relatively modest available stock of chromium-enriched bare wire and base plate, standard 70-30 cupronickel core wire and mild steel base plate were used initially. This was known to be feasible from previous experience which indicated that operation on cupronickel plate is usually better than on mild steel, so that welding on the steel is a stiffer test. Also, from the viewpoint of operation, coatings that operate well on standard 70-30 cupronickel generally operate well on chromium-enriched cupronickel.

After the preliminary screening had indicated the most promising formulae, the chromium-enriched core wire and plate were used for electrode testing. Since the 1/8" diameter core wire was supplied by the government in the form of 36" cut lengths, this material was cut into 12" lengths rather than the usual 14"; thus, we were able to get three usable electrode lengths from each 36" piece instead of two usable lengths and 8" of waste which use of the standard 14" length would have given. Use of the shorter length was deemed immaterial in view of previous experiences.

Results of Operational Tests and Pertinent Electrode and Formulae Data

The results of the operational tests and pertinent electrode and formula data are listed in Table I for all electrodes created for this contract. While a significant number of the experimental electrodes exhibited satisfactory all-position operation, the

weld metal soundness tests noticeably reduced the number of viable contenders. Also, feedback from the physical properties tests of Phase II and the pipe weld tests of Phase III necessitated more Phase I formula work so that formulation was essentially on-going for the duration of the project.

By extensive application of the formulation art and previous experience, we were eventually able to make an electrode which met the required specification MIL-E-22200/4B test 3 and the pipe weld criteria. Details are reported under Phase II and III work. However, we believe the final successful formula while workable and satisfactory,is susceptible to significant improvement by further development on a production scale.

Weld Metal Soundness

As originally proposed, the standard vertical plate, test 8a of specification MIL-E-22200/4B (see attached Exhibit A), was used as the preliminary soundness test. However, this test was supplemented by a modified 8a test welded with the groove tilted at a 45° angle (see attached Exhibit B). This is a much more rigorous test than the vertical plate and simulates reasonably well the rigors of actual pipe welding. It has often been used in both Naval and private shipyards to screen electrodes for pipe welding quality much more rapidly and economically than can be done by actual pipe welding. The soundness tests in both the 8a and modified 8a tests were made more rigorous by keeping grinding to essentially nil.

The results of all x-ray soundness tests are listed in Table II. Included are tests 8a, modified test 8a and test 3, the flat plate of specification MIL-E-22200/4B. For purpose of discussion, the causes and number of failures in the various soundness tests, their distribution, and the number of passing samples are listed herewith:

NO. OF FAILED PLATES AND CAUSES vs. PASSING PLATES

TEST	CRACKS	FUSION DEFECT	LINEAR INDICATIONS	INCLUSIONS	POROSITY	TOTAL FAILING	TOTAL PASSING
8a	4	1	--	--	2	7	15
Mod. 8a	4	1	2	3	1	11	8
3						0	8
TOTAL	8	2	2	3	3	18	31

Taken at face value, the failure figures would seem to indicate cracking as a major failure problem. However, in consideration of the fact that only two formulae in two different coating diameters each were involved, the overall weight of cracking as a failure cause becomes much less. This view is reinforced by the fact that the two formulas involved were the only ones giving cracks in these tests, and they happened to be coatings in which chromium had been added to produce about 2% chromium in the weld.

Also, excessive porosity in these tests proved to be somewhat less of a problem than had been anticipated. When porosity was a failure cause, it was not far beyond acceptable limits. The fusion defects were deemed to be partly formula deficiencies and partly welder error. Often, a welder will be more successful the second time around on a test because he has had some practice in dealing with the new formula.

As the pass-fail figures show, we were able to develop a significant number of passing samples as possible candidates for the pipe test. Consequently, we believe the 8a and modified 8a tests served well as effective screening devices for developing electrode coating formulae with good potential for successful pipe welding.

PHASE II

DETERMINATION OF EXPERIMENTAL ELECTRODE CAPABILITY TO MEET TENTATIVE CHEMICAL AND MECHANICAL PROPERTIES CRITERIA BY USE OF TEST NO. 3 OF SPECIFICATION MIL-E-22200/4B

PROCEDURE

Phase II attack was begun by selecting what was initially deemed the best Phase I electrode and testing it for tensile and bend properties according to test 3 of MIL-E-22200/4B (see Exhibit E). The flat plate of test no. 3 was used to check weld metal soundness in the flat position. Initial testing was sometimes done on standard cupronickel plate and then followed by testing on chromium-enriched cupronickel plate. This method was used as a means of proceeding progressively from a moderately difficult testing to the maximum difficulty since experience indicated greater ease in obtaining good results with standard cupronickel plate than with chromium-enriched cupronickel plate. It was also felt that the dual testing would contribute to our understanding of the different problems to be solved in the welding of the chromium-enriched plate. Experimental results are listed in Tables III and IV. Also, where a suffix letter such as "A" or "B" follows the sample number, the formula used is the same as that used for the same sample numbers where the letter suffix is not used. However, the letter indicates additional tests or tests under different conditions.

TENSILE PROPERTIES (TABLE III)

The tentative required tensile properties as noted in a tentative specification submitted to us May 22, 1973 by Mr. Ronald H. Leopold of NSRDC were:

YS	-	47,000 psi
TS	-	70,000 psi
El	-	20% min.

All of the samples tested easily met these requirements except for T11,792A-2. However, two re-test tensiles T11,792A-3 and T11,792A-1 did pass so that the tensile requirements are considered met by all samples tested.

BENDS TABLE III

Since no bend criteria were submitted to us, we arbitrarily chose to use as tentative requirements those listed in pp 3.3.2, BENDING, of MIL-E-22200/4B which says:

> "After bending the weld metal of each specimen shall be visually examined on the convex surface by the unaided eye and shall not exhibit evidence of fissuring in excess of two fissures each having a maximum length of 1/8-inch nor exhibit evidence of any fissuring over 1/8-inch long measured in any direction. Cracks occurring on the corners of a specimen during testing shall not be considered".

Since T11,220 the first sample bend-tested failed badly, other additional modified formulas had to be prepared and tested. Thus, samples T11,232 and T11,233 were welded in standard cupronickel plate and bend tested. Both samples gave perfect bends; consequently, both were welded in chromium-enriched cupronickel plate under test nos. T11,232A and T11,233A respectively. In each test, two bends were perfect while the third had three small fissures, one more than the two allowed by our arbitrary criteria.

In order to see if there are any weld metal compositional differences which could explain the difference in performance between the bends for the series comprising T11,232, T11,233, T11,232A and T11,233A, chemistry was run on the tensile bars from each sample. However, judging by the analyses results, we find no explanation here for the differences in bend performance.

To double check the bend capabilities, short plates yielding only three bends were welded in chromium-enriched plate using new batches of electrodes numbered T11,232R and T11,233R respectively. In each case, two out of the three bends were poor. We then concluded that formulas T11,232 and T11,233 were not sufficiently reliable where bend tests were concerned and additional formulae development was necessary.

Formulas T11,659 and T11,660 were then next selected for bend tests in the chromium-enriched cupronickel plate. All three T11,660 bends were acceptable while only one of T11,659 failed because of three small fissures rather than only the two allowed.

Since in Phase III pipe welding T11,659 and T11,660 did not pass,additional formulas T11,790, T11,791 and T11,792A were developed and subjected to test 3 after passing test 8a soundness

tests. All three met the tensile and bend requirements. T11,790 and T11,792A also passed modified test 8a and were scheduled for pipe welding. T11,791 was not given the modified 8a test or pipe test because its operation in test 8a seemed noticeably inferior to T11,790 and T11,792A.

In view of the foregoing and the results listed in Table III, we believe that electrodes giving acceptable bend properties have been achieved. However, we also tentatively conclude that the arbitrary tentative bend criteria we selected may be too severe for the chromium-enriched cupronickel weld metal deposited by the SMA process. For this higher strength cupronickel weld metal we believe at least three fissures, 1/8" maximum, might be an adequate and more reasonable bend requirement. An alternate suggestion might be the bend criteria as outlined in specification MIL-E-22200/3C for Monend electrodes, type 9N10. This allows 3 fissures 3/32" maximum for 1/8" electrodes.

WELD METAL SOUNDNESS (Test 3 - Flat Plate

All flat plates made for test no. 3 passed.

PLATE, CORE WIRE, PIPE AND WELD COMPOSITION (Table IV)

Plate, core wire, pipe, tentative weld deposit and actual weld deposit chemistry are listed in attached Table IV. Most actual weld deposit chemistries are reasonably close to the tentative required deposit analysis. Manganese, silicon, chromium and iron tended to run toward the high side of the proposed range and, in some cases, exceeded the tentative maximum. However, the highest value of any element did not exceed any value we could find reported in the literature as unequivocally harmful.

Since the present tentative required weld deposit composition is clearly not at all sacrosanct, we propose the following weld deposit chemical composition range:

ELEMENT	PRESENT TENTATIVE RANGE	ARCOS PROPOSED RANGE
C	.05	.05
Mn	1.2 - 2.0	1.2 - 2.50
Si	.20 - .50	.20 - .70
S	0.020	0.020
P	0.020	0.020
Cr	2.1 - 2.6	2.1 - 2.8
Ni	27 - 32	27 min.
Ti	0.1	0.2
Cu	bal	bal
Fe	0.25	0.80
Zr	0.2	0.2

Note: Single values are max. unless otherwise noted.

Our own experience to date and the available literature references indicate nothing detrimental in the proposed Arcos range. We believe this range will give needed latitude for improved electrode development in production lots.

There did not seem to be any outstanding compositional differences to explain variability in bends or soundness. However, since final compliance to the required criteria resulted, as changes in alloying metallics and deoxidizers were made, we conclude that the metallurgical quality of the weld metal was thereby significantly improved. We also believe a change in the balance of various non-metallic ingredients may have been a factor in the amelioration of results.

PHASE III

PIPE WELDING OF 4" NPS CLASS 700 PIPE

PROCEDURE

In accordance with our original proposal, pipe welding in government-supplied 4" NPS class 700 chromium-enriched cupronickel pipe was begun as viable electrodes were made available through the screening processes of Phases I and II previously described. The procedure used was test no. 9 (see Exhibit D) of specification MIL-E-22200/4A except that 4" instead of 5" diameter pipe was used because 4" was the only size the government had available in the chromium-enriched cupronickel alloy.

This 4" pipe had a wall thickness of only 7/32" which would normally be welded with a 3/32" electrode. Thus, an extremely severe demand for extraordinary performance was placed on our 1/8" electrode. Local heat build-up is very rapid in this relatively thin wall pipe at the amperage necessary to operate the normal 1/8" cupronickel electrode. Test 8a, the vertical plate of specification MIL-E-22200/4B, for example, specifies a minimum of 1/4" thickness for 3/32" electrodes and a minimum of 3/8" thickness for 1/8" electrode.

The pipe, x-rays and bend results are listed in Table V. Also, for radiographic purposes, this size pipe may be divided into as many as seven (7) segments (see attached Exhibit E) by the radiographer if he deems this necessary to maintain the required density tolerance over the entire length of each segment x-rayed. In the five pipe weldments x-rayed, the number of segments x-rayed per pipe varied from five to seven at the x-ray technician's discretion. In all cases, position 1 represented welding in the downhand position.

DISCUSSION OF PIPE X-RAY AND BEND TEST RESULTS

The first pipe weld was made with electrode T11,659A, a repeat of T11,659. This electrode was so promising from an operational viewpoint, that we proceeded with a pipe weld even though two modified test 8a attempts - one with the original T11,659 and the other with T11,659A, a repeat - had failed because of some inclusions. This pipe was divided into five segments for x-ray and failed in only the 1-2 segment by reason of a large inclusion. The remaining segments had acceptably small amounts of porosity. The two root bends passed but only one of the two face bends passed.

Formula revision was undertaken and T11,660A-type electrode which passed all three soundness tests was pipe welded next. T11,660A (repeat of T11,660 to get more electrodes) was the first T11,660 type pipe welded. All segments passed except 2-3 which had a small inclusion and segment 5-1 which had porosity beyond the allowable limit.

The two face bends passed but both root bends failed. The operation of the T11,660 type was excellent, being superior to T11,659. Consequently, since the T11,660A pipe weld was so close to passing, we decided it was worth another try in view of the possibility that welder experience gained on the first try might be all that was needed to get a successful pipe weld. Therefore, sample T11,660RR, a repeat of T11,660, was pipe welded. All segments passed except 4-5 which had a crack. In view of the second x-ray failure with this type of electrode, no bends were taken out of the pipe weldment.

Further formulation was done out of which emerged two viable pipe-welding candidates, T11,690 and T11,792A. Both samples passed all the screening tests of Phase I and II and both had excellent welding operation, especially T11,690. Thus, pipe welds were made with both samples. Out of seven segments of T11,790, four passed, but segments 5-6 and 6-7 were rejected because of crack-like indications; segment 4-5 was rejected for porosity. Thus, no bends were taken from this sample.

T11,792A passed the x-ray requirements in all seven segments although some porosity was noted in all seven. Both face bends and root bends passed. Thus, T11,792A was the first electrode to pass all the required tests.

DEMONSTRATION FOR NSRD

On Wednesday, February 2, 1977, Mr. Robert Maersch of NSRD visited our plant in Philadelphia to witness a demonstration of the chromium-enriched cupronickel electrodes developed here. Two samples were demonstrated - T11,792A and T11,919. The latter sample was not reported previously herein because it was made as a matter of our own interest after the contract work had been completed.

Both electrodes were welded in horizontal fillets, flat plate, and pipe. Both gave excellent operation in all three tests.

In our opinion, T11,919 was better. At Mr. Maersch's suggestion, we tried both electrodes on straight polarity in three flat plates. All previous tests had been done on DCRP. Both electrodes performed very well; again, we rated T11,919 as superior.

Finally, to tie down the real limits of the electrode vs. operation under various electrical conditions, we tried both electrodes on AC in horizontal fillets. Both electrodes were easily operable on AC although they tended to give more spatter. Again, we rated T11,919 as better.

Ten electrodes of each sample were given to Mr. Maersch for preliminary operational evaluation by NSRD welders.

SUMMARY

A three-phase program to develop a satisfactory all-position chromium-enriched cupronickel electrode pipe welding was undertaken. Various electrode coating formulae were developed and screened for welding operation by the use of horizontal and vertical fillets. Viable electrodes passing the fillet tests were further screened for weld metal soundness by test 8a of specification MIL-E-22200/4B and Arcos modified test 8a (see Exhibit B).

Electrodes showing promise in these soundness tests were tested for their ability to meet the tentative tensile property, bend and chemical composition criteria as well as weld metal soundness in the flat position by use of test 3 of specification MIL-E-22200/4B. Electrodes indicated by test 3 to have pipe-welding potential were then welded in 4" NPS class 700 chromium-enriched cupronickel pipe.

As the testing program progressed, feedback from the advanced testing dictated more electrode development which was then followed by subsequent full testing of new electrodes. This process continued until a satisfactory all-position chromium-enriched electrode capable of making pipe welds having adequate soundness and weld metal properties was finally attained in electrode T11,792A.

Present tentative tensile property criteria were deemed satisfactory. A modified weld metal composition range was suggested to facilitate further development of improved electrodes on a production scale without detriment to electrode performance or weld metal properties.

RECOMMENDATIONS FOR FUTURE WORK

1. Chemical Composition of Weld Deposit

   We recommend adoption of the revised chemical composition range listed on page 9 until further experience is attained.

2. Tensile and Bend Criteria

   The tentative tensile criteria listed in Table III are adequate for the time being and should be retained. For bends, three fissures 1/8" long but none over 1/8" should be permitted. Cracks 1/64" or under and those occurring on the corner of a specimen should not be counted. The foregoing criteria would always be subject to review and change as more experience with electrodes is attained.

3. Testing Weld Metal Soundness

   The present tests 3 and 8a of specification MIL-E-22200/4B should be quite adequate for testing weld metal soundness once a preliminary history of successful pipe welds is established in initial production runs.

4. Testing Weld Metal Properties

Test 3 of specification MIL-E-22200/4B is adequate.

5. Further Development and Establishment of a Production-Proven Electrode

The additional work done by Arcos outside of the contract shows that our first completely successful electrode, T11,792A is susceptible to operational improvement. Assuming continued interest by NSRD, we propose that a contract be placed for the manufacture of electrodes in 3/32" and 1/8" sizes in sufficient quantities for experimental use in several shipyards. The specification requirements should be as recommended previously. Adequate allowance should be made in the schedule for delivery of the electrodes for possible further formula modifications to accomodate problems encountered in electrode production facilities.

EXPLANATION OF TABLE I SYMBOLS

CuNi - std. 70Ni 30Cu wire or plate
CuNiCr - chromium enriched 70Ni 30Cu
MS - mild steel
SS - sodium silicate
PS - potassium silicate
FSM - fused synthetic material
E - excellent
VG - very good
G - good

F - fair
P - poor
HF - horizontal fillets
VF - vertical fillets
Welding Parameters
Current - DCRP
Amps - HF - 100-110
" VF - 80-85
Volts - 23

TABLE I

ELECTRODE DATA

SAMPLE NO.	CORE	NOMINAL ELEC. DIAMETER in inches	COATING TO CORE AREA RATIO	BINDER % SS	BINDER % PS	TEST PLATE	DEOXIDIZATION & REFINING SYSTEM	COATING VARIANTS	WELDING OPERATION HF	WELDING OPERATION VF
T10,874	CuNi	0.214	2.9	25	75	MS	Al,Si,Ti,Zr	1 FSM	VG	VG
T10,874A	"	"	"	100	-	"	Al,Si,Ti,Zr	1 FSM	E	VG
T10,875	"	"	"	25	75	"	Al,Si,Ti,Zr	1 FSM-increased amt.	VG	F+
T10,875A	"	"	"	100	-	"	Al,Si,Ti,Zr	1 FSM-increased amt.	G	F+
T10,876	"	"	"	25	75	"	Al,Si,Ti,Zr	2 FSM	F+	F+
T10,877	"	"	"	25	75	"	Al,Si,Ti,Zr	2 FSM-decreased amt.	G	F+
T10,877A	"	"	"	100	-	"	Al,Si,Ti,Zr	2 FSM-decreased amt.	G	F+
T10,878	"	"	"	25	75	"	Al,Si,Ti,Zr	3 FSM	VG	G
T10,878A	"	"	"	100	-	"	Al,Si,Ti,Zr	3 FSM	E	VG
T10,879	"	"	"	100	-	"	Al	1 FSM-high Ni & Cr	G	G
T10,879A	"	"	"	25	75	"	Al	1 FSM-high Ni & Cr	VG	F+
T10,880	"	"	"	25	75	"	Al,Si,Ti,Zr	Increased CaO & SiO_2	G	F+
T10,881	"	"	"	25	75	"	Al,Si,Ti,Zr	Increased FSM	P	P
T10,882	"	"	"	25	75	"	Al,Si,Ti,Zr	Increased Al_2O_3 & SiO_2	F+	F+
T10,896	"	"	"	25	75	"	Al,Ti	Increased Al and Ti	VG	F+
T10,912	"	0.200	2.6	60	40	"	Al,Si,Ti,Zr	1 FSM	E	F+
T10,913	"	"	"	60	40	"	Al,Si,Ti,Zr	3 FSM	VG	VG
T10,914	"	"	"	60	40	"	Al	1 FSM-high Ni & Cr	VG	F
T10,915	"	"	"	60	40	"	Al,Mg,Ti	1 FSM	VG	F
T10,916	"	"	"	60	40	"	Al,Mg,Ti	1 FSM-increased Al_2O_3 and SiO_2	E	F+

TABLE I (continued)

SAMPLE NO.	CORE	NOMINAL ELEC. DIAMETER in inches	COATING TO CORE AREA RATIO	BINDER % SS	BINDER % PS	TEST PLATE	DEOXIDIZATION & REFINING SYSTEM	COATING VARIANTS	WELDING OPERATION HF	WELDING OPERATION VF
T10,916A	CuNi	0.200	2.6	25	75	MS	Al,Mg,Ti	1 FSM-increased Al_2O_3 and SiO_2	VG	F+
T10,957	"	0.190	2.3	25	75	"	Al,Si,Ti,Zr	High Cr	VG	VG
T10,957A	"	0.214	2.9	25	75	"	Al,Si,Ti,Zr	High Cr	VG	VG
T10,958	"	0.190	2.3	25	75	"	Al,Si,Ti,Zr	none	G	G
T10,958A	"	0.214	2.9	25	75	"	Al,Si,Ti,Zr	none	VG	VG
T10,959	"	0.190	2.3	60	40	"	Al,Mg,Ti	1 FSM-increased Al_2O_3 and SiO_2	G	G
T10,959A	"	0.200	2.6	60	40	"	Al,Mg,Ti	1 FSM-increased Al_2O_3 and SiO_2	VG	VG
T10,960	"	0.190	2.3	60	40	"	Al,Mg,Ti	1 FSM-hi Cr, increased Al_2O_3 and SiO_2	VG	VG
T10,960A	"	0.200	2.6	60	40	"	Al,Mg,Ti	1 FSM- hi Cr, increased Al_2O_3 and SiO_2	VG	VG
T10,968	CuNiCr	0.214	2.9	25	75	CuNi	Al,Si,Ti,Zr	Lower Mn	VG	VG
T10,969	"	0.200	2.6	60	40	"	Al,Mg	1 FSM-increased Al_2O_3, and SiO_2	G	G
T10,970	"	"	2.6	60	40	"	Al,Mg,Ti	3 FSM	E	VG
T10,977	"	"	"	60	40	"	Al,Mg,Ti	1 FSM-increased Al_2O_3 and SiO_2	G	G
T11,220	"	"	"	60	40	"	Al,Mg,Ti	3 FSM (10,970 repeat)	E	VG
T11,232	"	"	"	60	40	CuNiCr	Al,Mg,Ti,Zr	3 FSM	G	F
T11,233	"	"	"	60	40	"	Al,Mg,Ti	3 FSM	G	F
T11,654	"	"	"	60	40	"	Al,Mg	3 FSM-	G	P
T11,657	"	"	"	60	40	"	Al,Mg,Zr	3 FSM-	G	P
T11,659	"	0.214	2.9	25	75	"	Al,Mg,Si,Ti,Zr	Zr lower	VG	VG
T11,660	"	0.200	2.6	25	75	"	Al,Mg,Ti	LiO_2 added, SiO_2 increased	VG	VG
T11,660B	"	0.195	2.4	25	75	"	Al,Mg,Ti	LiO_2 added, SiO_2 increased	G	F+
T11,660C	"	0.214	2.9	25	75	"	Al,Mg,Ti	LiO_2 added, SiO_2 increased	G	G

TABLE I (continued)

SAMPLE NO.	CORE	NOMINAL ELEC. DIAMETER in inches	COATING TO CORE AREA RATIO	BINDER % SS	BINDER % PS	TEST PLATE	DEOXIDIZATION & REFINING SYSTEM	COATING VARIANTS	WELDING OPERATION HF	WELDING OPERATION VF
T11,661	CuNiCr	0.200	2.6	25	75	CuNiCr	Al,Mg,Si,Ti,Zr	LiO_2 added, SiO_2 increased	F	G
T11,662	"	"	"	25	75	"	Al,Mg,Ti	LiO_2 added, SiO_2 increased	G	F
T11,789	"	"	"	-	100	"	Al,Si,Ti,Zr	High TiO_2	F	G
T11,790	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	1 FSM-Halide increased	E	E
T11,790A	"	"	"	60	40	"	Al,Mg,Si,Ti,Zr	" " " "	VG	VG
T11,791	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	1 FSM-Halide increased, carbonates revised	F	G
T11,792	"	0.190	2.3	25	75	"	Al,Mg,Si,Ti,Zr	Mg added	G	G
T11,792A	"	0.200	2.6	25	75	"	Al,Mg,Si,Ti,Zr	" "	E	VG
T11,792B	"	0.214	2.9	25	75	"	Al,Mg,Si,Ti,Zr	" "	G	G
T11,793	"	0.210	2.8	25	75	"	Al,Mg,Si,Ti,Zr	Ti added	G	F
T11,794	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	Increased halide & Mg	F	F
T11,795	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	Increased SiO_2 & Mg	F	P
T11,796	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	Increased Mg, halide change	G	G
T11,797	"	0.195	2.4	-	100	"	Al,Mg,Si,Ti,Zr	Increased Mg, high TiO_2	F+	F
T11,798	"	0.200	2.6	30	70	"	Al,Mg,Si,Ti,Zr	Increased Mg, 1 FSM	F+	F
T11,902	"	"	"	-	100	"	Al,Mg,Si,Ti,Zr	1 FSM, high TiO_2 halide change	P	P
T11,905	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	1 FSM-carbonate rev.	G	G
T11,906	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	" " " "	VG	VG
T11,907	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	" " " "	VG	VG
T11,908	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	" " " "	E	E
T11,909	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	" " " "	G	G
T11,910	"	"	"	25	75	"	Al,Mg,Si,Ti,Zr	1 FSM-carbonate & halide revision	G	VG

TABLE II

X-RAY DETERMINATION OF WELD METAL SOUNDNESS

TEST 8a-VERTICAL PLATE					MODIFIED TEST 8a - VERTICAL PLATE @ 45° TILT					TEST 3 FLAT PLATE	
PASSED		FAILED			PASSED		FAILED			ALL PASSED	
SAMPLE NO.	PLATE	SAMPLE NO.	PLATE	CAUSE OF FAILURE	SAMPLE NO.	PLATE	SAMPLE NO.	PLATE	CAUSE OF FAILURE	SAMPLE NO.	PLATE
T10,958A	CuNi	T10,957	CuNi	Cracks	T10,958A	CuNi	T10,957	CuNi	Cracks	T11,220	CuNi
T10,959	"	T10,957A	"	"	T10,959	"	T10,957A	"	"	T11,232A	CuNiCr
T10,959A	"	T10,958A	"	Porosity	T10,968	"	T10,958	"	Inclusions	T11,233A	"
T10,968	"	T10,960	"	Cracks	T10,970	"	T10,959A	"	Porosity	T11,659	"
T10,970	"	T10,960A	"	"	T11,660A	CuNiCr	T10,960	"	Cracks	T11,660	"
T11,220	"	T10,969	"	Porosity	T11,660C	"	T10,960A	"	"	T11,790	"
T11,232A	CuNiCr	T10,977	"	Fusion Defects	T11,790	"	T10,969	"	Fusion Defects	T11,791	"
T11,233A	"				T11,792A	"	T11,659	CuNiCr	Linear Indica.	T11,792A	"
T11,659	CuNiCr						T11,659A	"	Inclusions		
T11,659	CuNiCr						T11,660	"	"		
T11,660	CuNi						T11,660B	"	Linear Indica.		
T11,660	CuNiCr										
T11,790	"										
T11,791	"										
T11,792A	"										

WELDING PARAMETERS

Current - DCRP
(Test 8a & Modified test 8a) Amps - 85 to 90
(Test 3) Amps - 105 - 110
Volts - 23

WELDING PARAMETERS

Current - DCRP
Amps - 105-110
Volts - 23

TABLE III

TENSILE PROPERTIES AND BEND RESULTS AS DETERMINED BY TEST NO. 3 OF SPECIFICATION MIL-E-22200/4B

SAMPLE NO.	PLATE		YS	TS	EL	RA	BENDS (three specimens)			COMMENT
	CuNi	CuNiCr	psi	psi	%	%				
Tentative Spec. Requirement		X	47,000	70,000	20	-----	Two fissures 1/8" max. Ignore corner cracks.			
T11,220	X		50.5	73.4	30	47.6				
			50.1	73.8	30	47.6	5-rej.	break-rej.	break-rej.	
T11,232	X		54.1	79.9	27	43.6	sound	sound	sound	Short plate.
T11,232A		X	58.9	79.4	24	48.7	3 @ 1/32"-rej.	sound	sound	
			61.3	82.6	23	40.8				
T11,232R		X					2 @ 1/64"-acc.	1 @ 1/4"-rej.	1 @ 1/4"-rej.	Short plate-bends only.
T11,233	X		53.3	77.5	28	44.8	sound	sound	sound	Short plate.
T11,233A		X	58.7	80.6	29	43.4	sound	2 @ 3/64"-rej. 1 @ 1/64"-rej.	sound	
			60.1	83.4	25	51.3				
T11,233R		X					2 @ 1/32"-acc.	7 - rej.	many rej.	Short plate-bends only.
T11,659		X	61.4	86.1	27	36.6	2 less than 1/32" - acc.	3 less than 1/32"-rej.	2 less than 1/32"-acc.	
			61.3	84.2	22	46.8				
T11,660		X	59.5	82.1	30	48.9	2 @ 1/32"-acc.	sound	1 less than 1/32" - acc. 1 less than 1/16" -acc.	
			59.6	82.4	28	46.2				

TABLE III (continued)

TENSILE PROPERTIES AND BEND RESULTS AS DETERMINED BY TEST NO. 3 OF SPECIFICATION MIL-E-22200/4B

SAMPLE NO.	PLATE CuNi	PLATE CuNiCr	YS	TS	EL	RA	BENDS (three specimens)		
Tentative Spec. Requirement		X	psi 47,000	psi 70,000	% 20	% --	*Two fissures 1/8" max. Ignore corner cracks.*		
T11,790		X	57.5	80.4	26	43.5	1 @ 1/64" -acc. 1 @ 1/16"-acc.	sound	1@ 3/64"-acc.
			48.0	82.4	26	44.1			
T11,791		X	57.3 56.7	79.0 78.7	27 26	43.2 49.6	1 @ 1/32"-acc.	sound	sound
T11,792A		X	65.9 63.2	90.3 75.0	25 *6	53.1 8.3			
T11,792A-3**		X	64.1	92.2	26	45.6			
T11,792A-4		X	64.4	90.3	23	38.8			

* 1/8" weld defect in cross section near circumference.

** Repeat tests.

TABLE IV

COMPOSITION OF PLATE, WIRE, PIPE AND WELD DEPOSITS

	C	Mn	Si	S	P	Cr	Ni	Ti	Al	Cu	Fe	Sn	Pb	Zn	Zr	Mg
+ Std. CuNi Plate	---	.70	---	.001	.002	---	29.66	---	---	64.95	.58	---	---	.02	---	---
++Govt. CuNiCr Ht. P9085	0.025	0.61	0.03	---	---	2.92	29.56	0.04	---	bal.	0.17	---	---	---	0.13	---
++Core Wire Ht. 2337	0.01	1.54	---	---	---	2.62	29.95	0.06	---	65.34	0.01	---	---	---	0.12	---
++Pipe Analysis Ht. 3663	0.004	0.84	0.06	---	---	3.12	30.49	0.05	---	bal.	0.04	---	---	---	0.13	---
Tent. Weld Deposit Spec.	0.05	1.2-2.0	.2-.5	0.020	0.020	2.1-2.6	27-32	0.1 max	---	bal.	0.25 max.	--	---	---	0.[illegible] max.	---
T11,232A	.026	2.21	.45	.004	.012	2.69	31.99	.075	.024	63.21	.27	<.005	<.005	<.005	.02	<.005
T11,233A	.028	2.21	.39	.006	.011	2.67	31.01	.065	.015	63.74	.26	<.005	<.005	<.005	.01	<.005
T11,232R	.014	2.23	.49	.010	.008	2.74	30.87	.062	.023	63.30	.10	<.005	<.005	<.005	.01	<.005
T11,233R	.014	2.21	.39	.008	.008	2.65	31.03	.053	.015	63.71	.56	<.005	<.005	<.005	.01	<.005
T11,232T *	---	2.20	.52	----	----	2.53	-----	.055	----	-----	.112	----	---	----	----	-----
T11,233T *	---	2.20	.41	----	----	2.43	-----	.047	----	-----	.24	----	---	----	----	-----
T11,659	.014	1.73	.66	.008	.009	2.46	31.54	.070	.013	63.79	.12	<.005	<.005	<.005	.01	<.005
T11,660	.013	2.33	.56	.005	.011	2.39	30.66	.065	.12	63.00	.17	<.005	<.005	<.005	.02	.015
T11,790	.010	2.65	.59	.011	.006	2.52	30.51	.065	.024	63.42	.21	.004	.003	.012	.064	.037
T11,791	.010	3.08	.51	.013	.005	2.60	30.30	.060	.028	63.21	.23	.002	.002	.008	.040	.027
T11,792A	.017	1.89	.82	.010	.003	2.39	32.24	.075	.016	62.05	.27	.004	.002	.008	.060	.059

* "T" denotes analysis from tensile bar chips. Scope of analyses was limited due to lack of availability of chips.

\+ Chemistry as certified by plate supplier.
++ Chemistry as given by Government for government-supplied plate, wire, & pipe.

EXPLANATION OF SYMBOLS

A - Acceptable   I-Inclusions
C - Crack   PN-Porosity Noted
CLI-Crack-like Indication
F - Fissures   R-Reject

TABLE V

X-RAY & BEND RESULTS FROM WELDS MADE IN 4" NPS CLASS 700 CHROMIUM-ENRICHED CUPRONICKEL PIPE

	PIPE SEGMENTS							BENDS			
								ROOT		FACE	
SAMPLE NO.	1-2	2-3	3-4	4-5	5-1* 5-6	6-1* 6-7	7-1	NO. 1	NO. 2	NO. 1	NO. 2
T11,659A	R-I	A-PN	A-PN	A-PN	A-PN*	--	--	A	A	R-5F	A
T11,660A	A-PN	R-I	A-PN	A-PN	R-PN*	--	--	R-4F	R-2F>1/8"	A	A
T11,660RR	A-PN	A-PN	A-PN	R-PN	A-PN	R-C*		No bends made because of x-ray failure.			
T11,790	A-PN	A-PN	A-PN	R-PN	R-CLI&PN	R-CLI&PN	A-PN	" " "	"	" "	"
T11,792A	A-PN	A-PN	A-PN	A-PN	A-PN	A-PN	A-PN	A	A	A	A

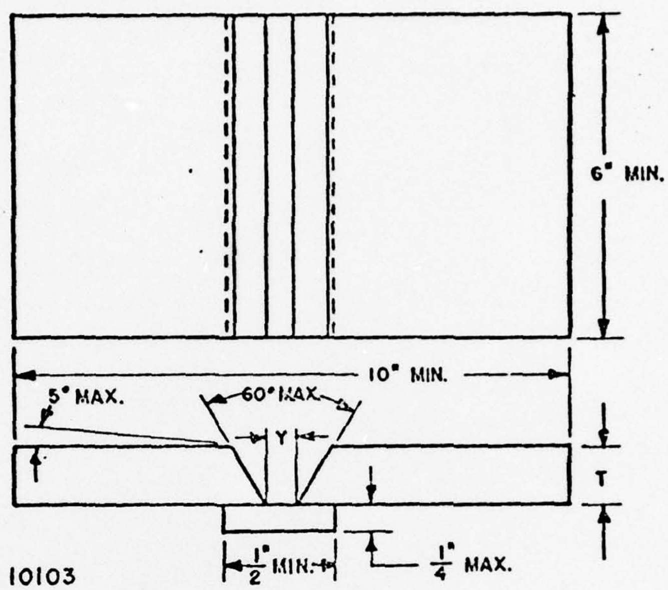
*Note: Where the x-ray laboratory elected to use less than 7 segments, the final segment number is listed in parentheses.

Welding Parameters

Current - DCRP
Amps - 85-90
Volts - 23

EXHIBIT A

Test 8a



SH 10103

.Electrode size	3/32 (Inch)	1/8 (Inch)	5/32 (Inch)	3/16 (Inch)
Thickness (T) Min.	1/4	3/8	1/2	1/2
Root opening 1/	1/4	5/16	3/8	1/2

1/ Tolerance ± 1/16 inch.

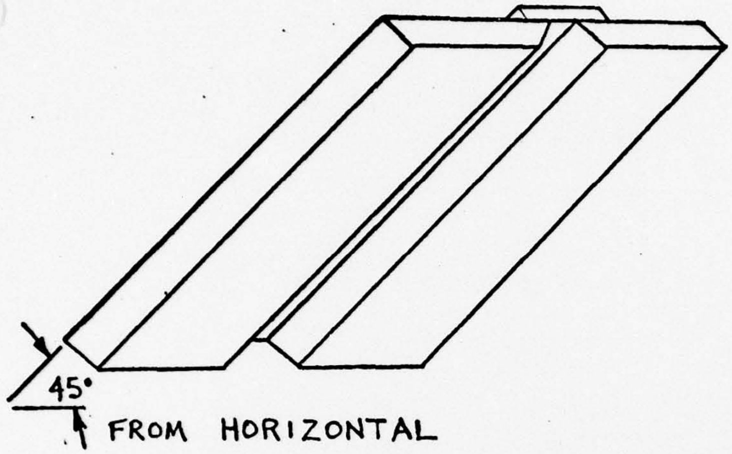
Notes to figure 2:

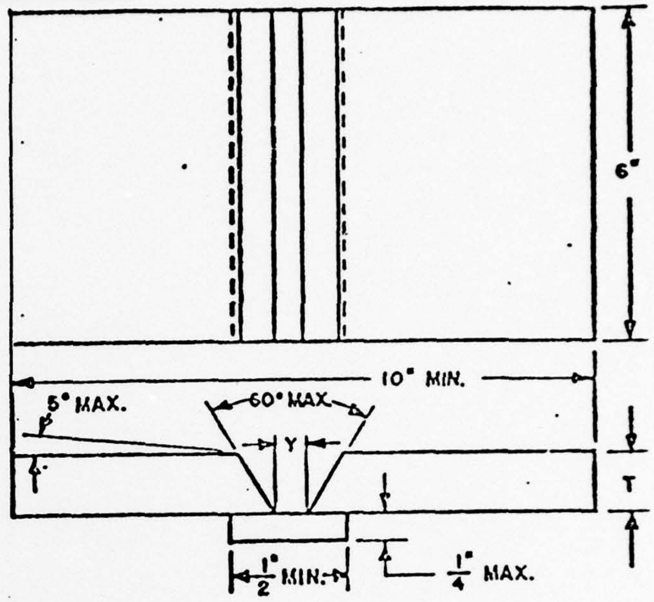
1. Welding shall be accomplished in the vertical or flat position as specified in table VI.
2. Base metal shall be in accordance with MIL-C-15726 or ASTM B122.
3. The bevel edge preparation shall be machined or ground.
4. Welds shall be deposited in approximately 1/8 inch thick layers. Each weld bead shall contain a start in the area to be evaluated. Weld deposits shall be made using a 3 core wire diameter maximum weld weave. The root weld layer may be deposited with 3/32 or 1/8 inch diameter electrodes when testing 3/16 inch diameter electrodes.
5. The completed weld reinforcement shall be 3/16 inch maximum.
6. Preheat shall not be employed. Interpass temperature shall be 150°F. maximum.
7. After completion of the weld, the weld reinforcement and backing strip shall be removed flush with base plate surfaces and the assembly shall be X-rayed in accordance with MIL-STD-271.
8. The radiographs shall meet the acceptance standards of NAVSHIPS 0900-003-9000 as specified in 3.7.1 of MIL-E-0022200E.

Figure 2 - Groove weld usability test (test No. 8a).

EXHIBIT B

Arcos Modified Test 8a





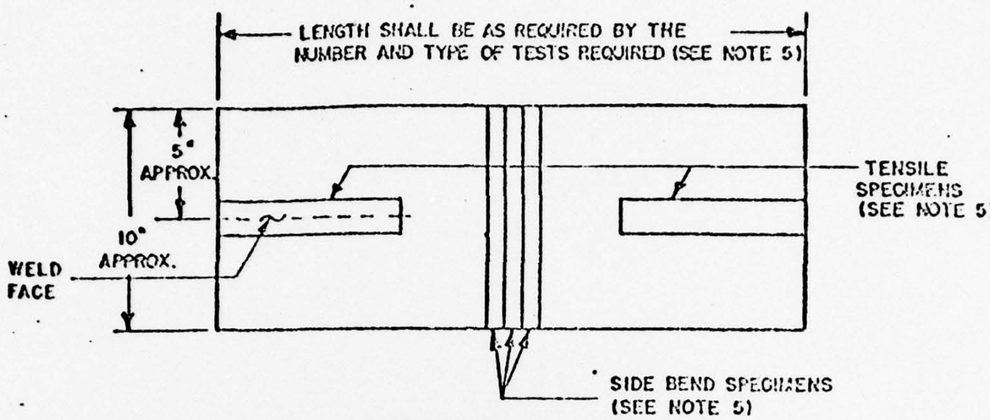
WELDING POSITION

.Electrode size	3/32 (Inch)	1/8 (Inch)	5/32 (Inch)	3/16 (Inch)
Thickness (T) Min.	1/4	3/8	1/2	1/2
Root opening [1]	1/4	5/16	3/8	1/2

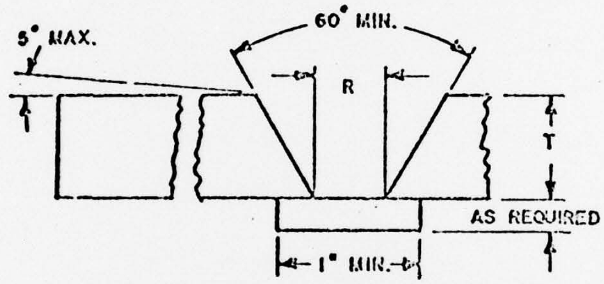
[1] Tolorance ± 1/16 inch.

EXHIBIT "C"

Test No. 3



LAY OUT OF TEST PLATE



GROOVE PREPARATION OF TEST PLATE

SH 10102

Electrode size	Minimum thickness (T)	Maximum root opening (R)	Number of layers 1/	
			Minimum	Maximum
(Inch)	(Inch)	(Inch)		
3/32	1/2	1/4	1/	1/
1/8	1/2	1/4	1/	1/
5/32	3/4	1/2	6	9
3/16	3/4	1/2	6	9

1/ Pass and layer sequence shall be recorded and reported.

Figure 1 - Welded joint for all-weld-metal tension test and bend test (test No. 3).

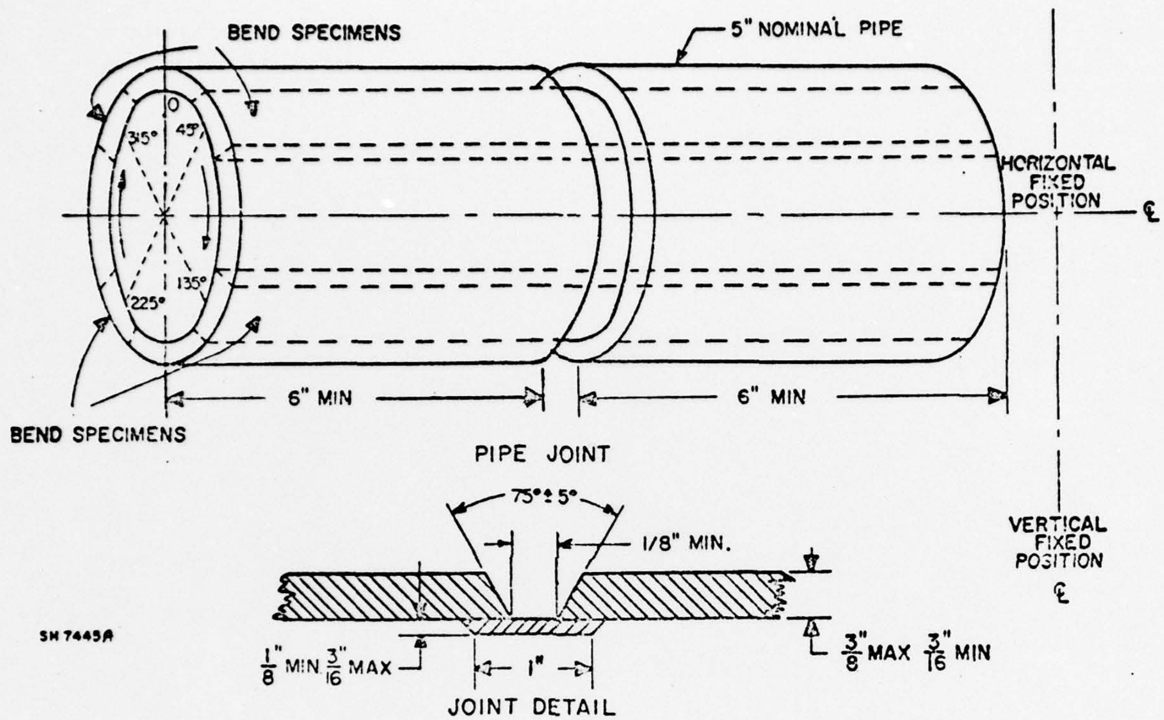


Figure 4 - Pipe usability test.

Notes to figure 4:

1. Piping shall be in accordance with MIL-T-16420.
2. Pipe joint shall be welded in the horizontal and vertical fixed positions as specified (see tables IV and V).
3. Standard pipe welding technique shall be used.
4. No preheat shall be used. The interpass temperature shall be 212°F.
5. Amperage and voltage shall be in accordance with electrode manufacturer's recommendations; conditions shall be recorded, preferably graphically.
6. Upon completion and cooling of the weld, the backing ring shall be removed, the weld surface ground smooth and the joint X-rayed in accordance with MIL-STD-271.
7. Guided bend coupons shall be removed from weldment at four locations, as illustrated in figure 4. Bend specimens shall be prepared and tested in accordance with MIL-STD-418 (see tables III and VIII.)
8. One specimen taken from 45° or 135° positions and one, from 225° or 315° positions shall be root-bend tested (root-side of weld in tension); the remaining specimens shall be face-bend tested.

EXHIBIT E

DIVISION OF 4" NPS CLASS 700 PIPE
INTO SEGMENTS FOR RADIOGRAPHY